River Systems

Best Practices in Dam and Levee Safety Risk Analysis

Part H – Other Risks

Chapter H-4

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US Army Corps of Engineers

U.S. Department of the Interior Bureau of Reclamation

Department of Energy Federal Energy Regulatory Commission

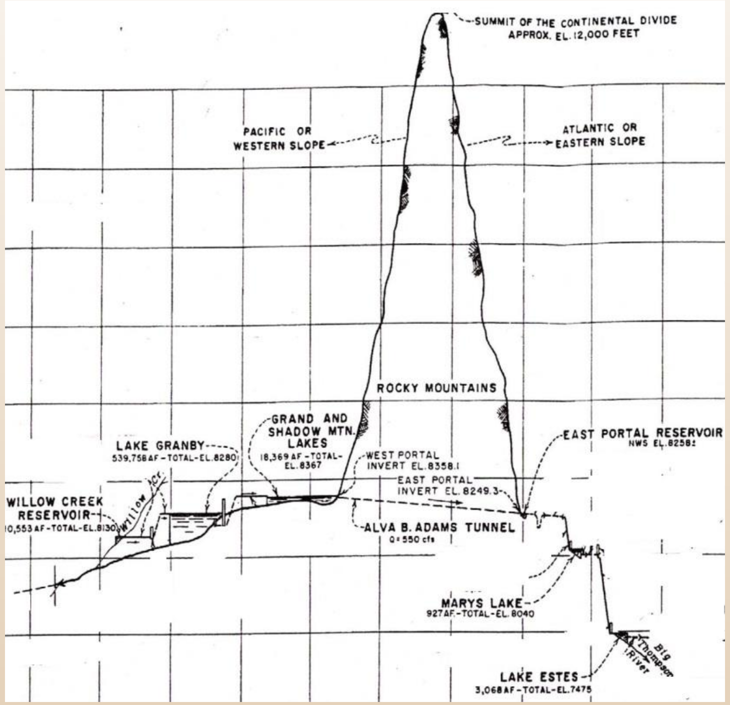
TVA

Outline

- Background
- Individual vs. System Risk
- Precedence and Causality
- Assigning “Blame”
- Dam Safety Modification Study (DSMS) Example
- Broader System Risk Considerations

Definition

- The systems risk approach looks at the combined risks associated with multiple facilities.
- This approach is of interest when the controlling risks at multiple facilities are the function of a common triggering event (e.g. a flood on the same river)



Background

Applicability

- DSMS studies involving hydrologic PFMs whose estimated risks are tied to the ability to pass or not pass a flood (i.e. overtopping PFMs)
- Examples presented here limited to two dams/levees in series on a given river
- Note that the decision to move to corrective action would be based on the risks associated with an individual facility

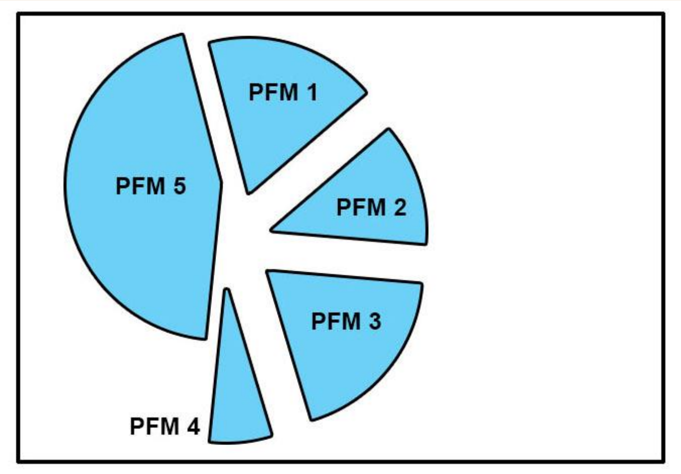
Basic Motivation

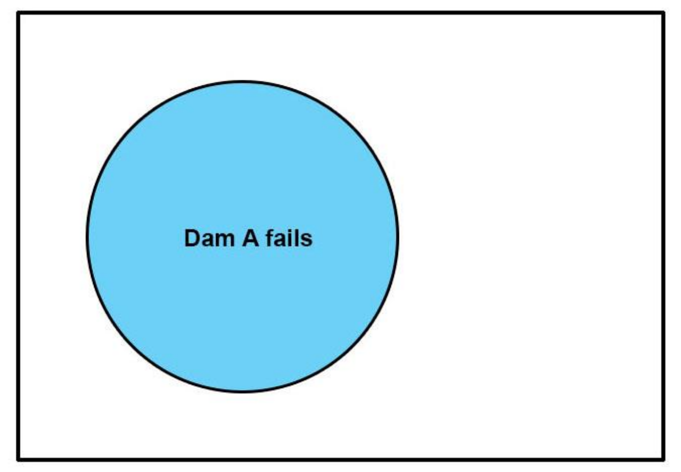
- To develop a more cost effective fix for the facility that is the primary focus of the corrective action study by distributing some of the modification work (and some of the risk) to other dams in the system
- To lower the overall risk associated with the system of dams/levees

Individual vs. System Risk

Individual versus System Risks

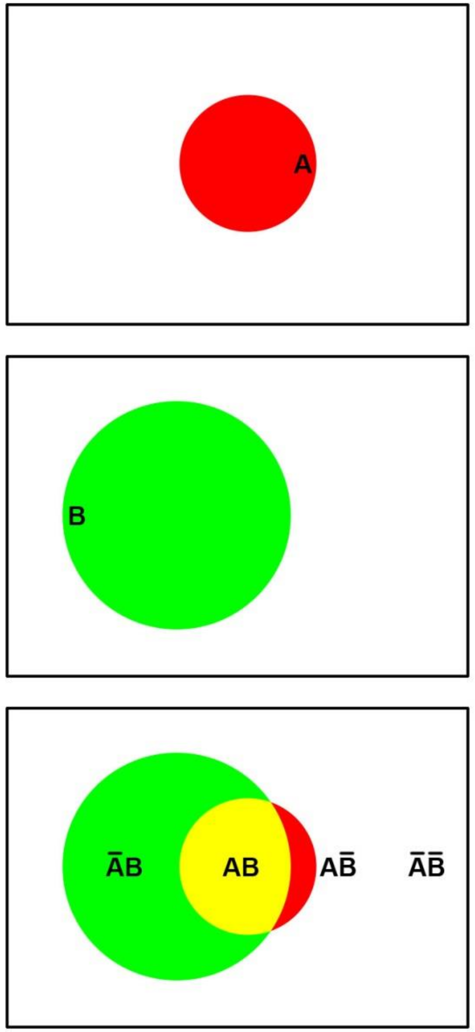
- For an individual facility, the risk is estimated in terms of potential failure modes. The PFMs are often treated as Mutually Exclusive events or transformed via the common cause adjustment (CCA)
- For ME PFMs, the occurrence probabilities of the individual PFMs (the AFPs) can be summed to obtain the total probability of dam failure





Individual versus System Risks

- Considered individually, a pair of dams has a total of two failure outcomes, A (Dam A fails) and B (Dam B fails). In contrast, a system of two dams has three failure outcomes (Dam A fails, Dam B fails, both dams fail)
- Note that the system failure probability is not equal to the sum of the probabilities of the individual-dam fail outcomes
- Note that whereas the Venn diagram intersection event AB describes the failure of both dams, the occurrence of the AB event does not imply that upstream dam fails 1st

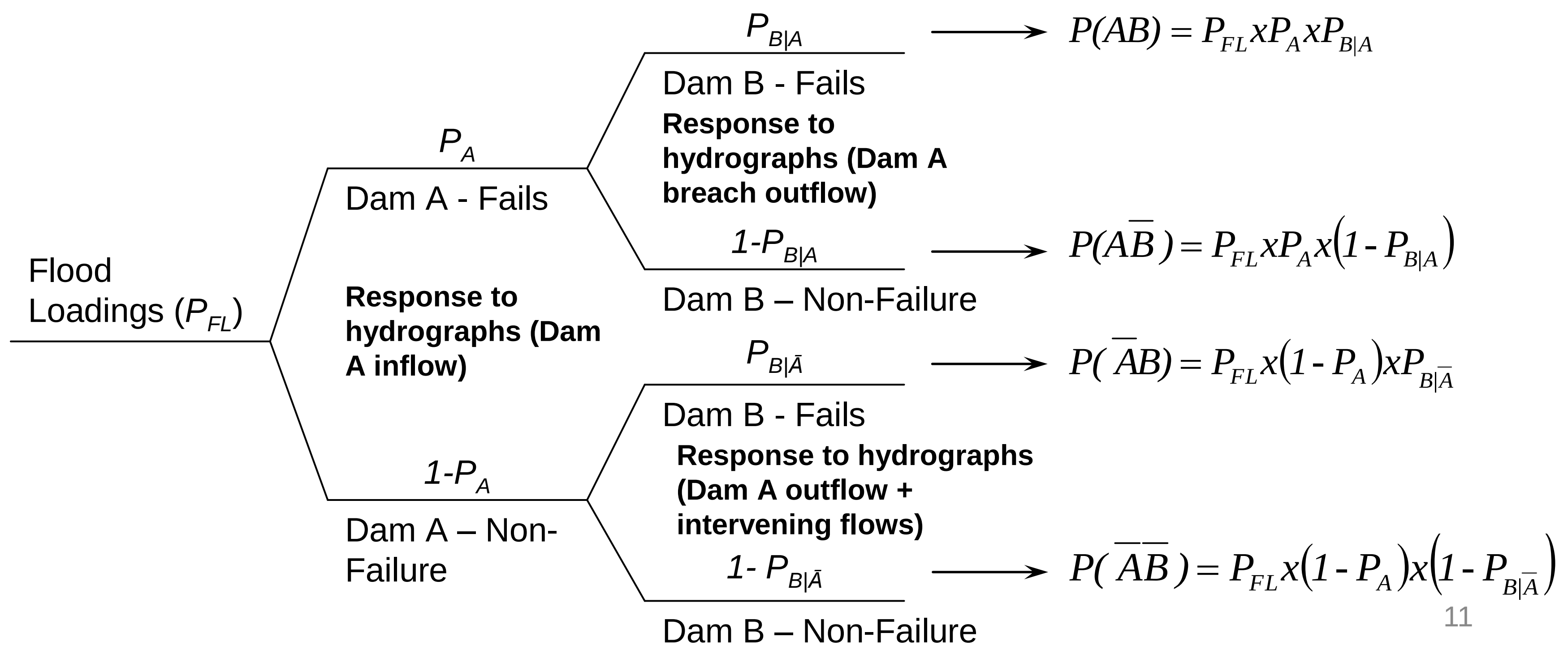


$$P(Fail_{SYS}) = P(\bar{A}B) + P(AB) + P(A\bar{B})$$
$$P(Fail_{SYS}) \neq P(A) + P(B)$$

Precedence and Causality/ Assigning “Blame”

Precedence and Causality

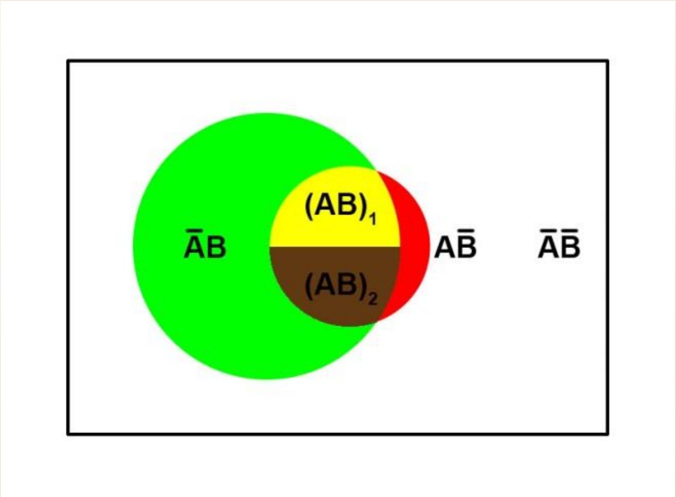
- The following event tree implies that if both dams fail, A fails first
- Can lead to confusion if the Dam B individual-dam risk estimates are not premised on non-failure of A

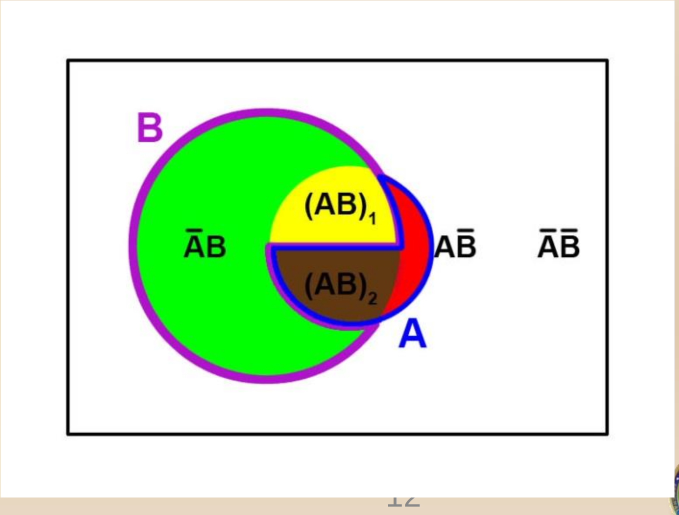


Assigning “Blame”

- In order to allocate and understand risk, the event AB can be decomposed into the ME events AB_1 (Dam A fails before Dam B) and AB_2 (Dam B fails before Dam A)
- The total system AFP is equal to the occurrence probability of the four* system fail events
- This total AFP can be reallocated to the individual dams that make up the system
- Helps identify which dam is really “above guidelines”
- *Note: if we increase to 3 dams in series, the possible outcomes increase to 15

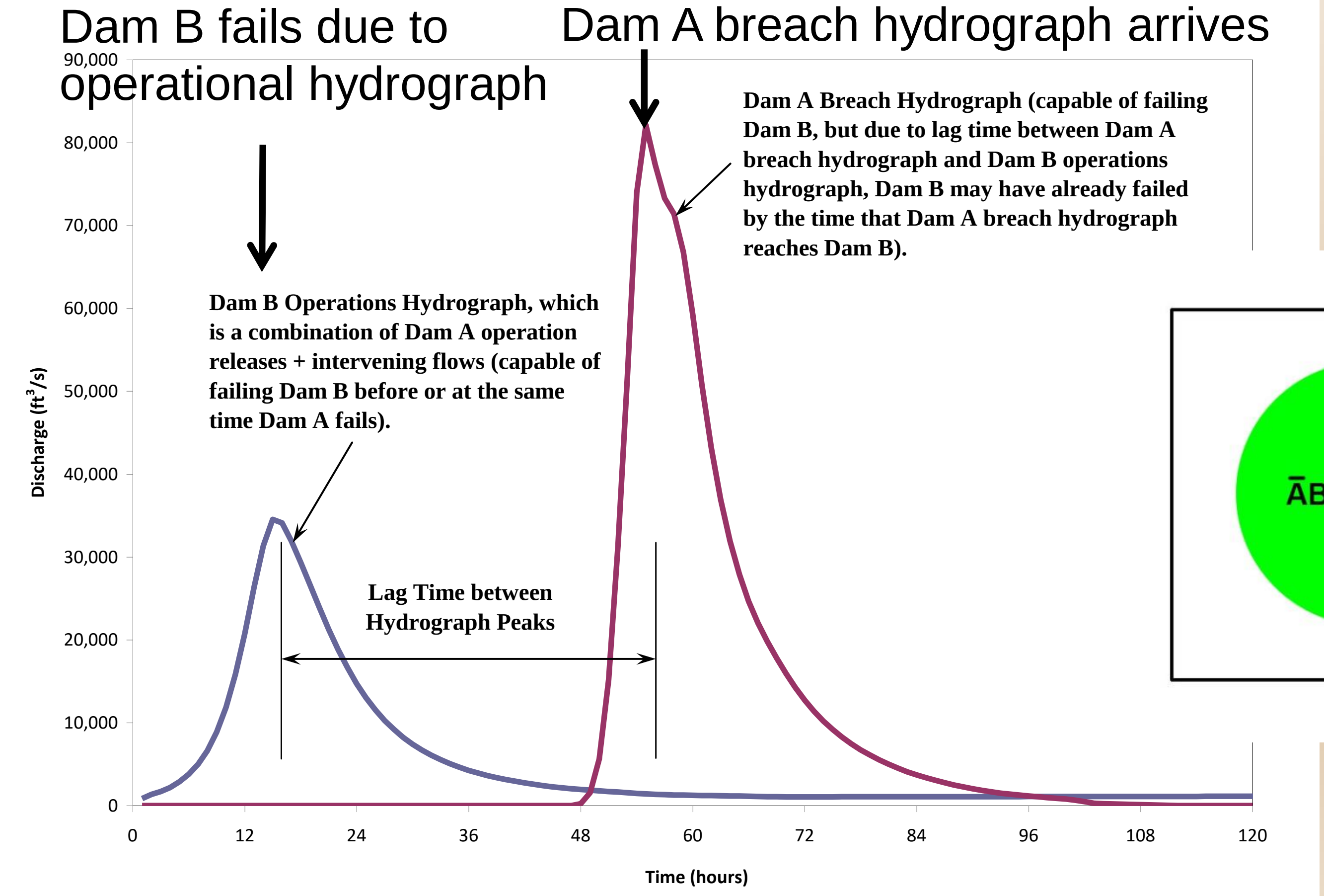
$$P(SYS) = P(\bar{A}B) + P(AB)_1 + P(AB)_2 + P(A\bar{B})$$

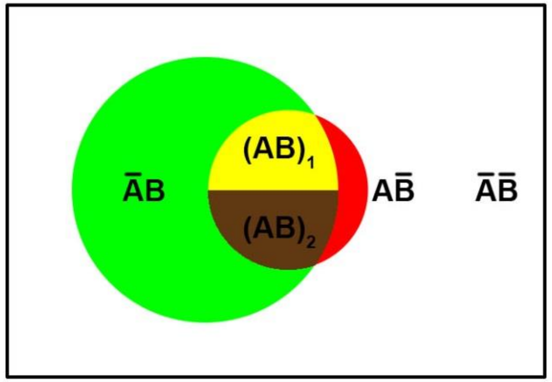




Assigning "Blame"

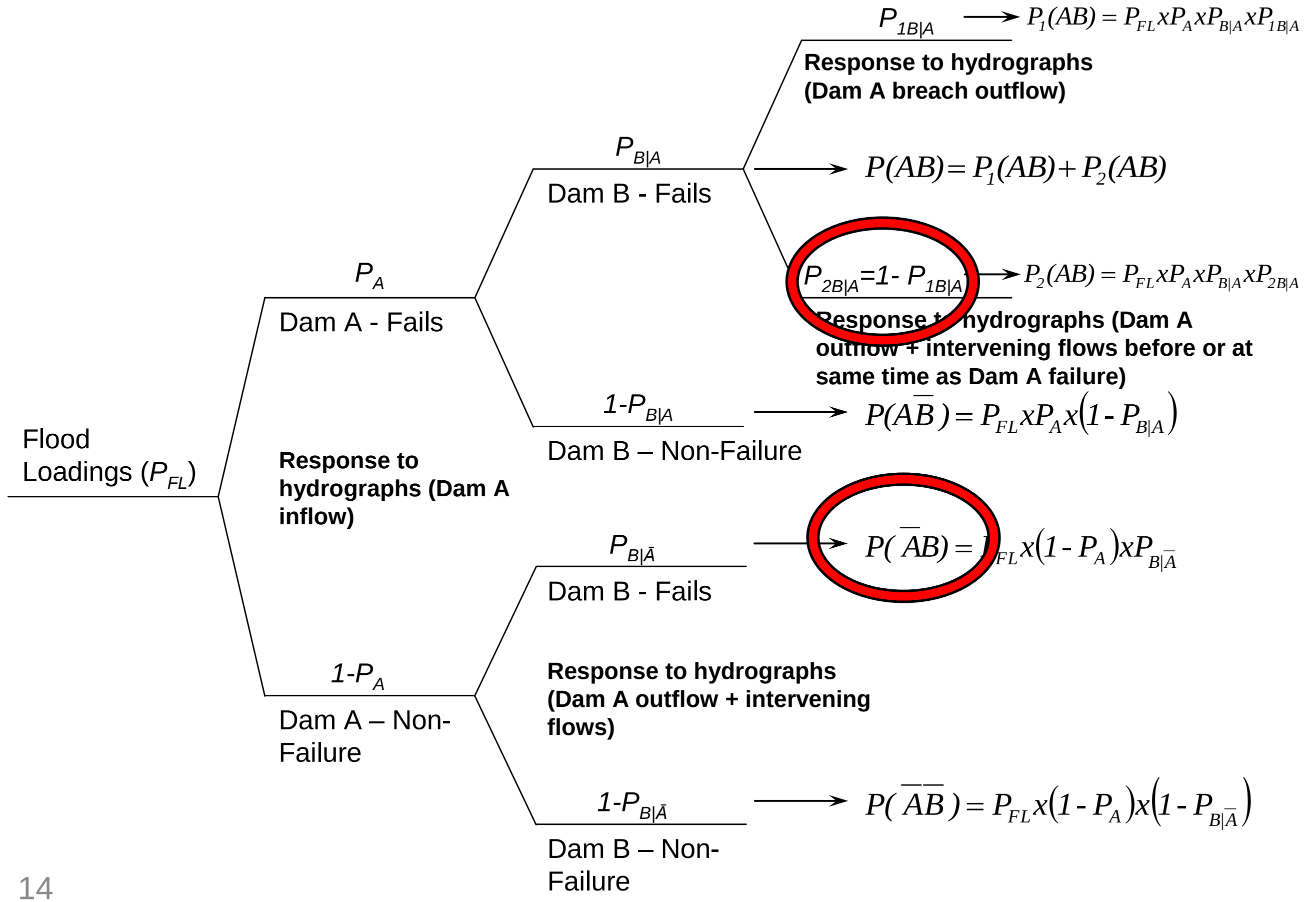
- If both dams fail, but B fails before the breach hydrograph reaches it, A may not be "to blame"





Assigning "Blame"

- In this case, the following sub-AFPs can be summed to obtain P(B)



Hydrologic Loadings

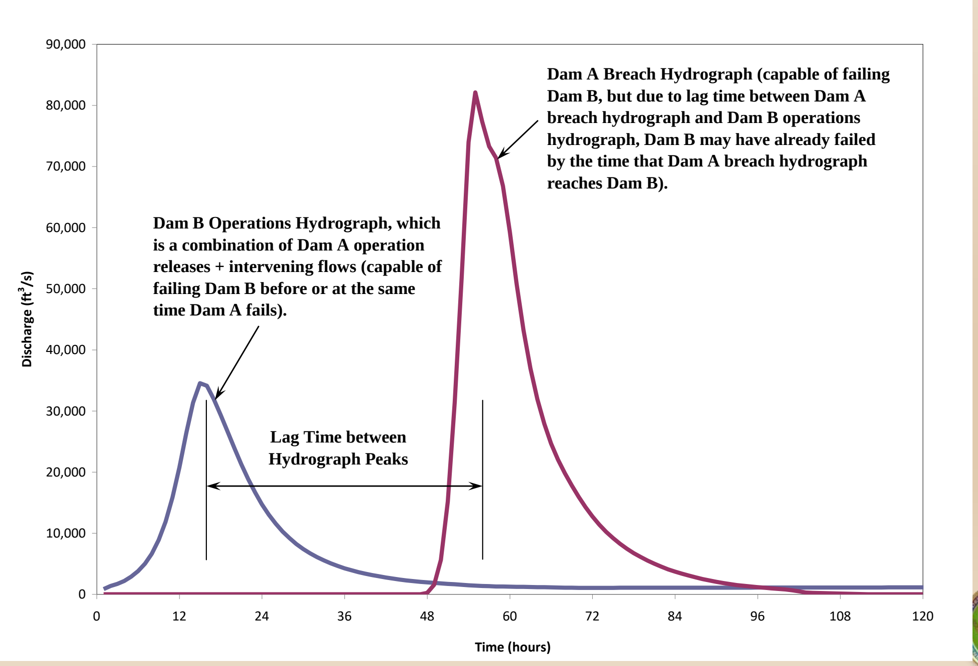
- Case 1:
  - High degree of confidence that upstream dam breach hydrograph (rather than the operation hydrograph) will cause failure of downstream dam(s)
    - Typically the case when the dams are close together and the intervening flows are limited, such that most precipitation is upstream of both dams

Case 2:

Uncertain which hydrograph (operational vs breach) will cause failure of downstream dam(s)

Often the case when the dams are far apart and/or there are major tributaries entering the river between the dams

May require distinct operational and breach hydrographs to be generated



Dam Safety Modification Study Example

DSMS Example

- Given:
  - 2 dam system, both embankments. -
    - Dam A (upstream).
    - Dam B (downstream) (Note, this could also be a downstream levee)

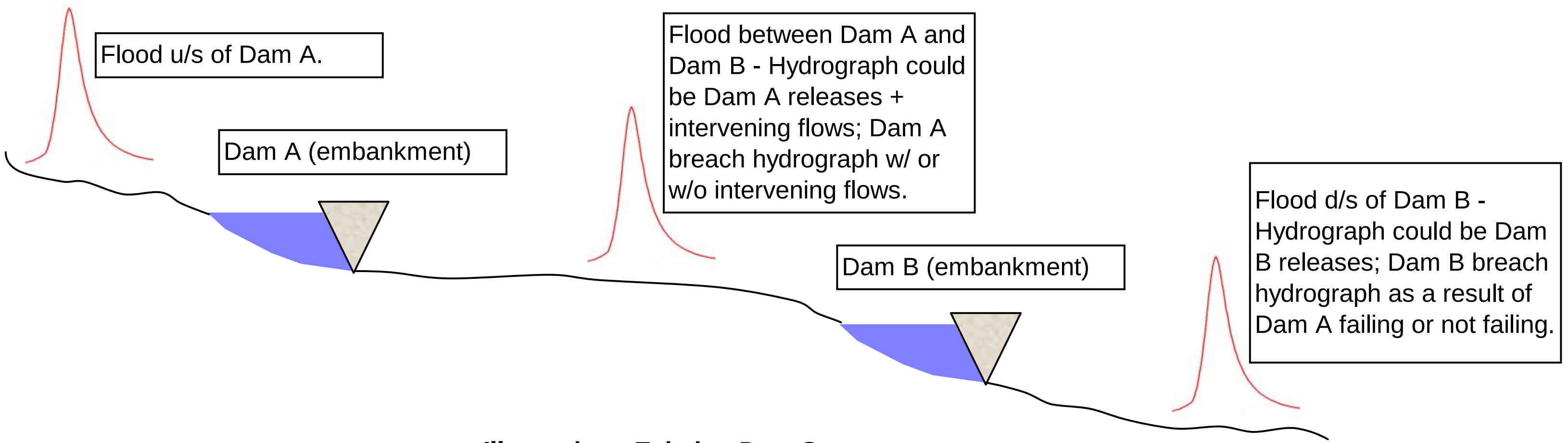


Illustration - Existing Dam System

DSMS Example

System Description	
Dam A: • **Reservoir –** 1,000,000 ac-ft. • **Zoned embankment –** H_{STR} = 200 ft., L_{CREST} = 1,400 ft. • **Spillway –** Location – reservoir rim, controlled (gated), Q_{DESIGN} = 75,000 ft^3/s. • **Outlet Works –** Location – right abutment tunnel, Q_{DESIGN} = 7,500 ft^3/s. • **Powerplant –** Location – Wyes off of OW near d/s portal, Q_{DESIGN} = 3,000 ft^3/s.	**Dam B:** • **Reservoir –** 45,000 ac-ft. • **Zoned embankment –** H_{STR} = 90 ft., L_{CREST} = 2,500 ft. • **Spillway –** Location – right abutment, uncontrolled (ogee), Q_{DESIGN} = 25,000 ft^3/s. • **Outlet Works –** Location – left abutment tunnel, Q_{DESIGN} = 3,000 ft^3/s.

DSMS Example

- Individual Dams Approach - Hydrology and Flood Routing:
  - Both Dam A and B periodically evaluated as part of the Dam Safety Program.
  - Seasonal frequency floods and PMFs have been developed.
    - Rain-on-snow (Feb through mid-Jun).
    - Thunderstorm (mid-Jun through Aug).
  - Basic flood routings available for both dams.
    - Frequency flood routings through Dam A over a range of starting RWS’s.
    - Operation flood (Dam A releases + intervening flows w/o Dam A failing) routings through Dam B over a range of starting RWSs.

DSMS Example

- Individual Dams Approach - Consequences:
  - Inundation studies for both max. operation releases and breach outflows for Dam A and B were available
  - Incremental consequences summary (breach minus non-breach) includes:
    - Dam A (includes Dam B breach) – Life loss = 100.
    - Dam B only – Life loss = 60.

DSMS Example

- Individual Dams Approach - Baseline RA:
  - Overtopping response curves developed for each dam.
  - Overtopping PFM event trees were developed for each dam, which included initial RWS ranges, flood loading ranges, and conditional breach probabilities based on response curves.
    - For Dam A: AFP = 7.35E-6, Ann. Life Loss = 7.35E-4.
    - For Dam B: AFP = 6.46E-5, Ann. Life Loss = 3.87E-3.

Unadjusted non-system (individual dam) estimates

  - Based on risk estimates
    - For Dam A, no further action recommended.
    - For Dam B, SOD recommendation made for DSMS to reduce risks.

DSMS Example

- Individual Dams Approach, Risk Reduction for Dam B:
  - Ability to pass at least a 500,000-yr rain-on-snow flood would reduce risks to below guidelines and so this flood was identified as the IDF.
  - Both non-structural and structural alternatives were evaluated. The recommended alternative cost estimate was $45,000,000 and included:
    - 20-ft dam raise.
    - Replace existing uncontrolled spillway w/ controlled (top-seal radial gate) spillway w/ larger discharge capacity.
    - Relocate/modify existing infrastructure located along the reservoir rim.
  - Estimated revised risks with modifications in place:
    - For Dam A: Same as existing conditions.
    - For Dam B: AFP = 1.88E-6, Ann Life Loss = 1.13E-4.

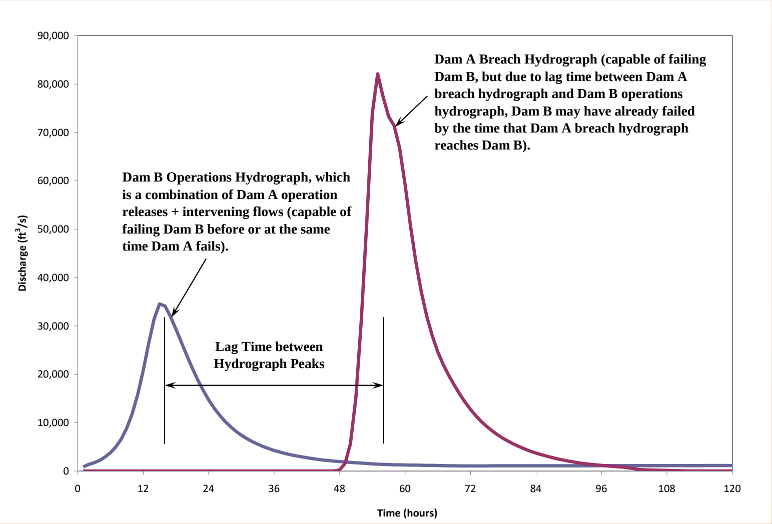
Unadjusted non-system (individual dam) estimates

DSMS Example

- Individual Dams Approach - Risk Reduction for Dam B (cont'd):
  - Although risk reduction can be achieved via the proposed alternative, costs were considered very significant (due primarily to relocating/modifying existing infrastructure).
- Systems Approach
  - To determine if there was a more cost-effective alternative, the risk reduction efforts were broadened to a system evaluation.

DSMS Example

- Dam System - Flood Routings:
  - Flood routings through both dams.
    - Frequency flood routings through Dam A over a range of starting RWSs were performed.
    - Operation flood (Dam A releases + intervening flows w/o Dam A failing) and breach hydrograph routed d/s to Dam B, then through Dam B over a range of starting RWSs.
    - Due to lag time estimates, multiple-peak hydrographs (time separation between operation flood and breach flood) were determined to be most likely.



DSMS Example

- Dam System - Consequences:
  - Incremental consequences varied from the individual dams evaluations for Dam A and Dam B.
  - Changes resulted from outcome associated with Dam A failing and Dam B not failing and due to the multiple-peak hydrographs.
  - Incremental consequences summary:
    - Dam A (includes Dam B breach) – Life loss = 100.
    - Dam A (without Dam B breach) – Life loss = 80.
    - Dam B (multiple-peak hydrograph) – Life loss = 60.

DSMS Example

- Dam Systems - Existing (baseline) RA:
  - Overtopping response curves developed for the individual dams evaluation were used for the system evaluation.
  - **Overtopping PFM event tree was developed for dam system**, which included initial RWS ranges, flood loading ranges, and conditional breach probabilities based on response curves.
    - For Dam System: AFP = 6.87E-5, Ann Life Loss = 4.15E-3.
    - For Dam A: AFP = 7.86E-7, Ann Life Loss = 7.85E-5.
    - For Dam B: AFP = 6.82E-5, Ann Life Loss = 4.09E-3.

Adjusted system individual dam estimates

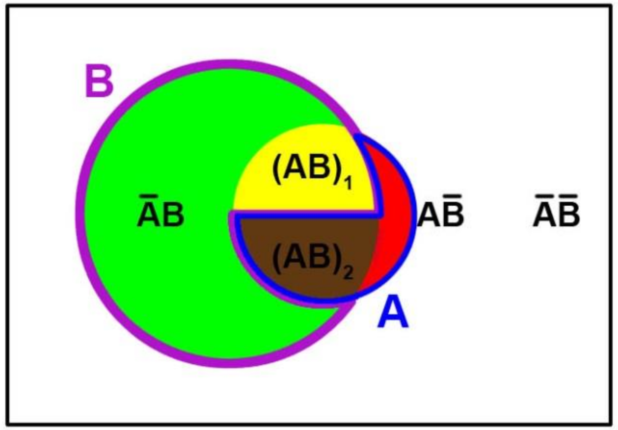
  - Outcome from risk estimates.
    - Based on Dam A and B risks for Dam System A-B, SOD recommendation made, that led to IES and DSMS to reduce system risks.
    - There is an event tree to estimate system risks if modifications are made to A, B, or both.

DSMS Example

- Dam Systems - Risk Reduction Dam A-B:
  - Three dam system structural modifications were considered, including:
    - Modify Dam B only. – Same modification as noted for the individual dams evaluation. $45,000,000 cost
    - Modify Dam A only. – 8-ft dam raise and increased releases through existing controlled (top-seal radial gate) spillway. $28,000,000 cost
    - Modify Dam A only with Re-operation. – 10-ft dam raise and limit releases through existing controlled spillway. $30,000,000 cost

DSMS Example

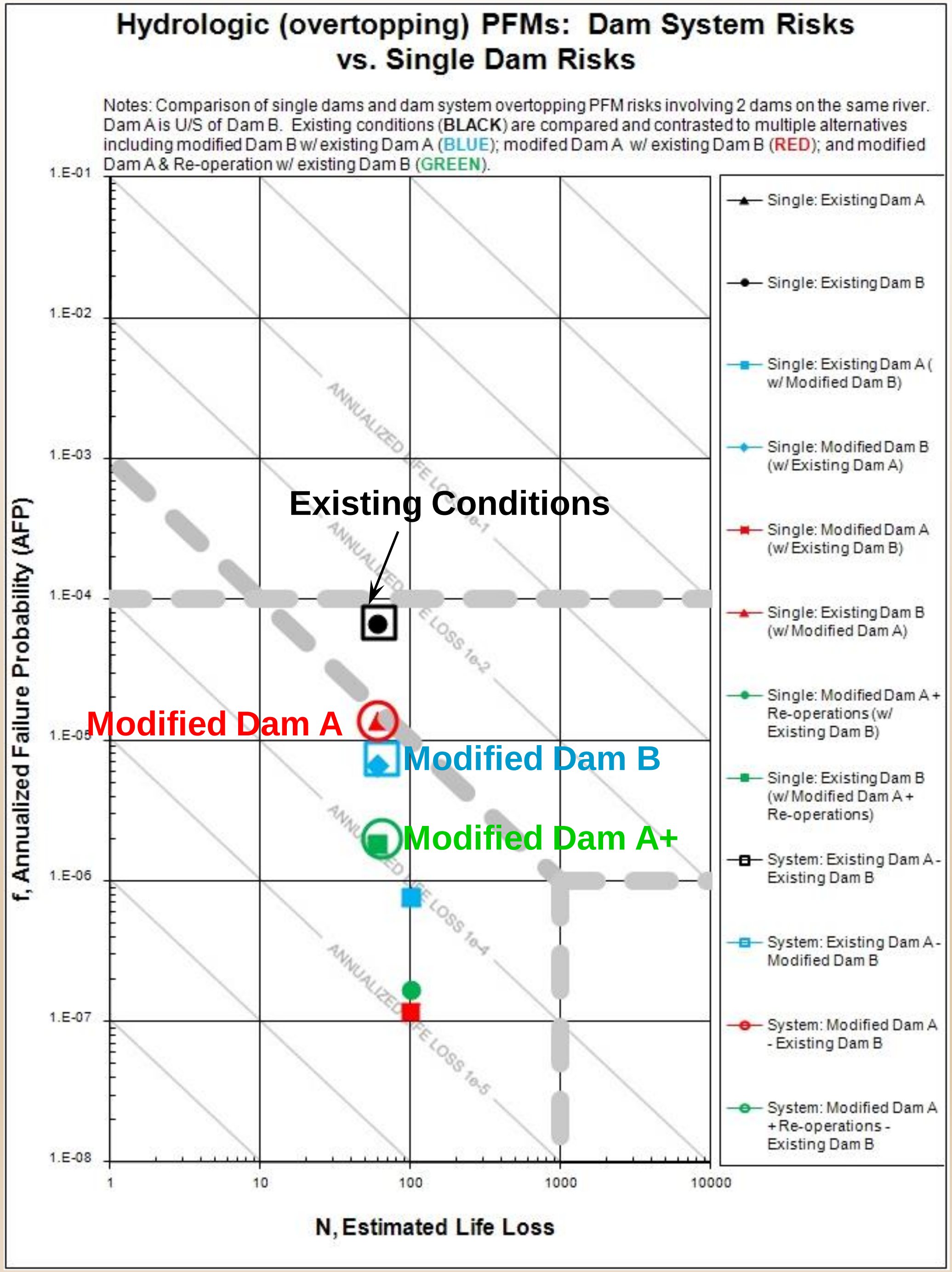
- Adjusted individual dam risks and system risks are summarized in the following table.



Conditions	Single Dams (Adjusted for system)				System – Dam A-B	
	Dam A		Dam B			
	AFP	A Life L	AFP	A Life L	AFP	A Life L
Existing	7.86E-7	7.85E-5	6.82E-5	4.09E-3	6.87E-5	4.15E-3
Mod Dam B	7.67E-7	7.60E-5	6.59E-6	3.95E-4	7.36E-6	4.71E-4
Mod Dam A	1.18E-7	1.17E-5	1.38E-5	8.26E-4	1.39E-5	8.38E-4
Mod Dam A + Re-Op	1.70E-7	1.70E-5	1.83E-6	1.10E-4	2.00E-6	1.27E-4

DSMS Example

- Dam Systems - Risk Reduction
  - Adjusted individual dam and dam system risks (pre- and post-mod) as depicted in the Reclamation f-N Chart. Circled symbols represent total system risk under the proposed alternative.

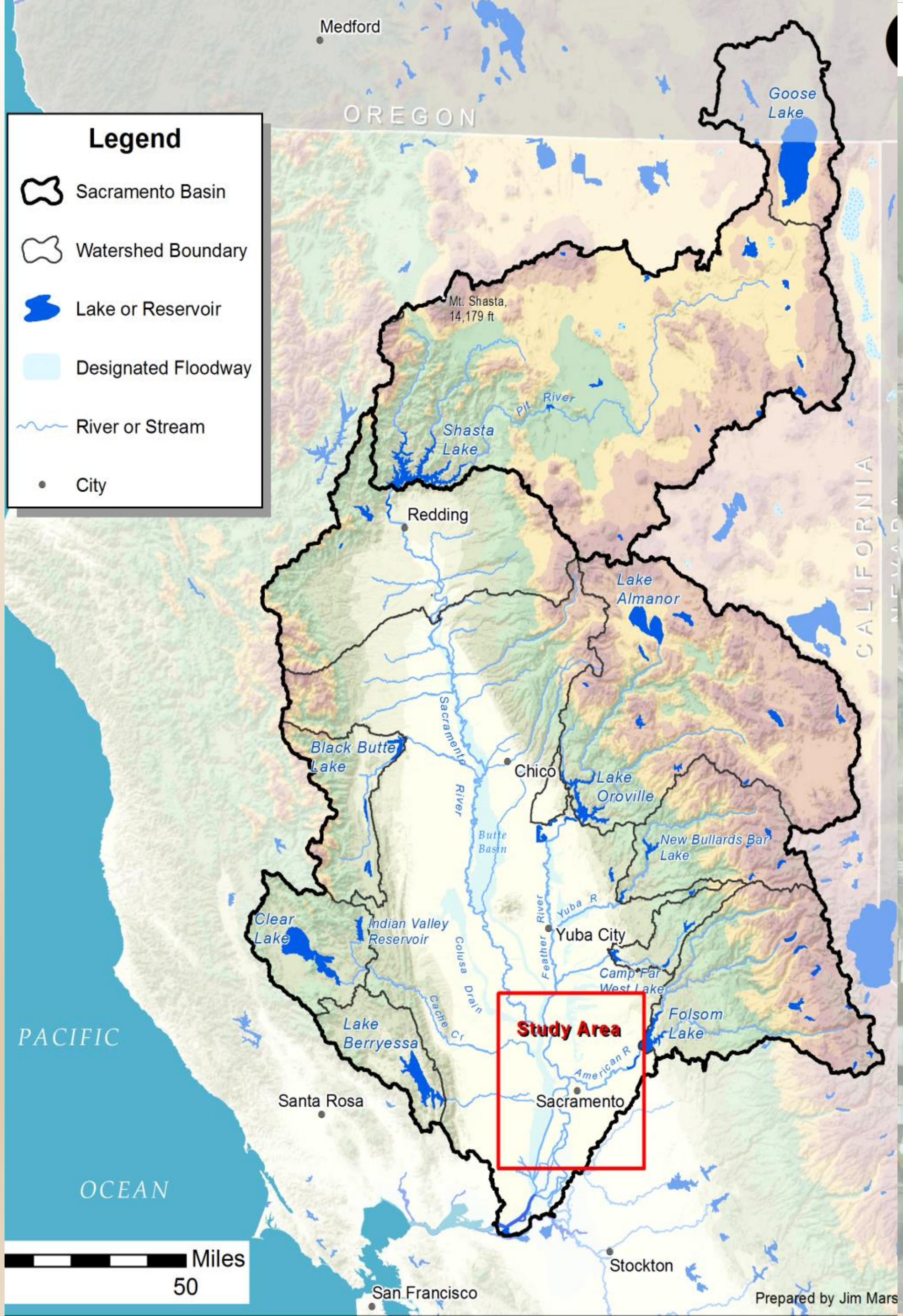


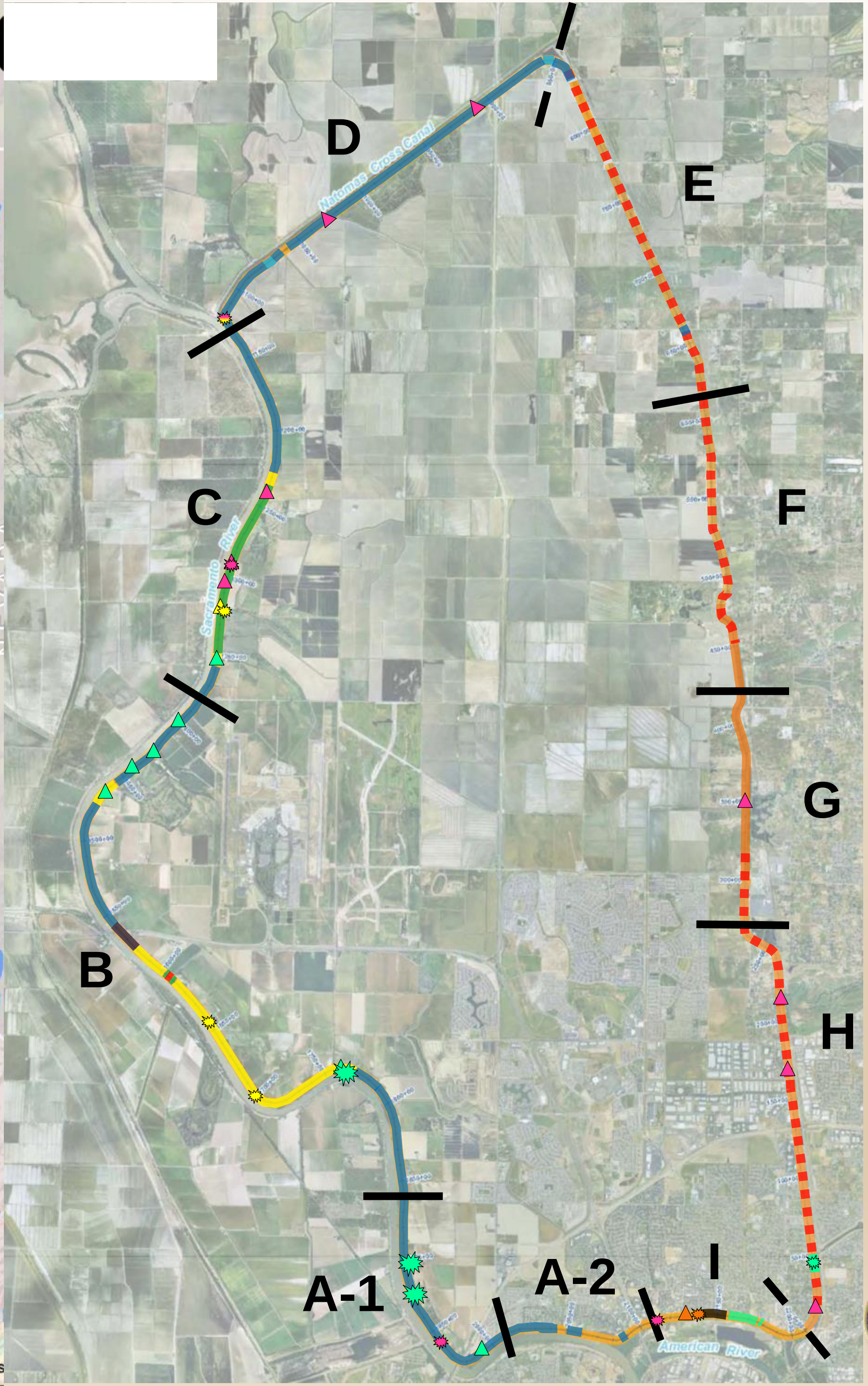
DSMS Example - Conclusions

- Modify Dam B only option – very expensive system fix, and so was not pursued.
- Modify Dam A only option – least cost system fix, but transfers some risk downstream to Dam B (which already had high risks) due to increased Dam A discharges. This alternative was not pursued.
- Modify Dam A only with re-operation – although a bit more expensive than the "modify Dam A only" alternative, considerably more risk reduction results. It was decided that the added system risk reduction was well worth the additional cost.
- Best alternative was arrived at from systems approach, not looking at dams individually.

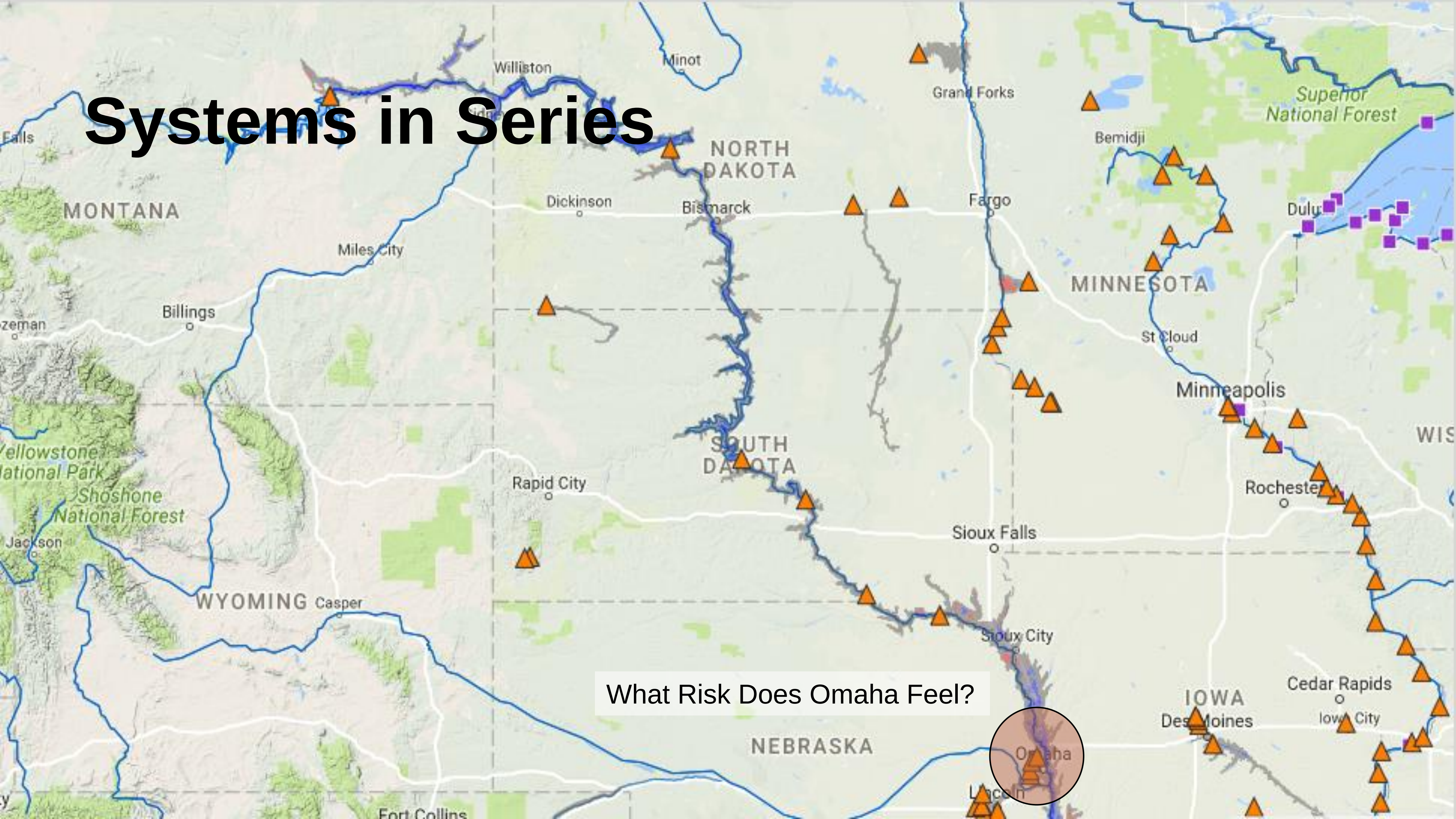
Broader System Risk Considerations

Levee System





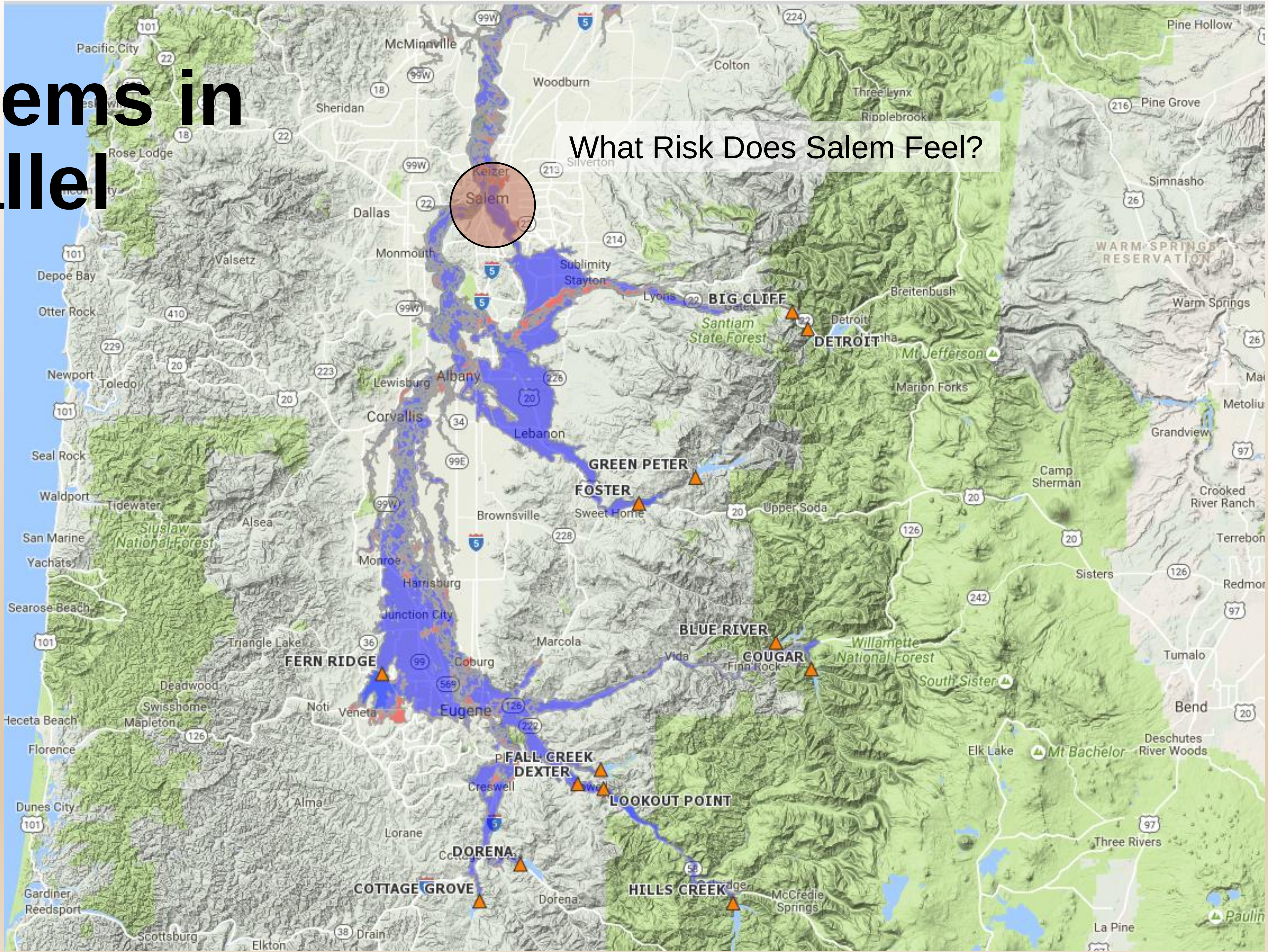
Systems in Series



What Risk Does Omaha Feel?

Systems in Parallel

What Risk Does Salem Feel?



Willamette Valley - System

Dams

- Fern Ridge
- Cottage Grove
- Dorena
- Dexter
- Fall Creek
- Lookout Point
- Hills Creek
- Cougar
- Blue River
- Foster
- Green Peter
- Detroit
- Big Cliff

Levees

- Keizer River Wall
- Kingston
- D.B. Gray
- Scofield
- Gavette
- Chamberlin
- Hamby-Helm-Mitchell
- Grice-Miller
- Walterville
- Santiam Fork
- Albany Golf Club
- Mitchell
- McCormick
- Lebanon City
- McNutt-McKenzie
- Long Tom
- Amazon Creek
- Fisher

Key Principles

- USACE, USBR, TVA, and FERC have all agreed NOT to assess risk for dams outside each agency's responsibility
- This is important for assumptions to portray system risk:
  - Structures owned or regulated by other agencies are assumed to perform as intended
  - This includes structures in series (downstream and upstream) and structures in parallel (on other drainage basins)
  - Structures owned or regulated by other agencies that are impacted by the structure being evaluated are counted as consequences of failure – some simplifying assumptions will often need to be made regarding these downstream structures

Key Principles (cont.)

- System risk is not part of any agency’s risk guidelines (the guidelines are referenced to a single structure or project)
- However, knowing the system risk is useful for agencies and owners
- System risk is most useful is assessing risk reduction alternatives once a decision has been made to modify a structure
  - It may be possible to develop more cost effective solutions by considering other structures in the system
  - The objective is to reduce the overall system risk and risk felt by the population downstream

Takeaway Points

- System risk evaluation is useful during dam safety modification studies to reduce overall system risk in a cost-effective manner
- The approach is relatively simple when only two dams are involved
- As more structures and features are added, the system risk evaluation becomes increasingly complicated – and a different more simplified approach may be needed than the example presented here

Questions/Comments?